Special issue of neuropsychologia

Editorial for Special Issue of Neuropsychologia: Semantic Cognition

The study of semantic cognition has a long history, in which neuropsychological studies have played a pivotal role. It was Wernicke's studies of aphasia that led to the proposal that concepts are formed through the linking of sensory-motor experiences (Wernicke, 1874) and echoes of this idea remain influential today. In more recent times, Elizabeth Warrington provided the first systematic investigation of patients with selective semantic disorders, of the type we would now recognise as semantic dementia (Warrington, 1975). As we reach the 40th anniversary of this landmark study, the syndrome remains a potent source of information about the semantic system, as shown by the number of studies in this special issue that include data from semantic dementia patients or make reference to the syndrome.

When functional neuroimaging techniques arrived on the scene in the 1980s and 1990s, aspects of semantic cognition were among the first to be explored (e.g., A. Martin, Wiggs, Ungerleider, & Haxby, 1996; Petersen, Fox, Posner, Mintun, & Raichle, 1988; Wise et al., 1991). These studies employed the now-familiar mass univariate analysis approach, which independently tests the effect of an experimental manipulation on the activity of each voxel in the brain. This technique remains important today but technical and computational advances have added new tools to the neuroimager's armoury: in particular, measures of structural and functional connectivity plus multi-voxel approaches that allow researchers to investigate how information is coded across brain regions (Norman, Polyn, Detre, & Haxby, 2006). For those of us interested in how the brain codes information – and this is, after all, the core function of the semantic system – these methods represent an exciting development. A number of papers in this special issue used some form of multi-voxel analysis to probe the semantic processing capabilities of the brain.

Other techniques for probing the semantic system include the use of transcranial magnetic stimulation to modulate or temporarily disrupt processes within specific cortical regions (Walsh & Cowey, 2000) and the direct recording and disruption of neural activity using implanted cortical electrodes in surgical patients (e.g., Lüders et al., 1986; Shimotake et al., in press), and these methods are also represented amongst the papers in this special issue. This is a field that continues to benefit from comparisons of different techniques, since historically, studies of patients with semantic dementia and those employing functional magnetic resonance imaging came to very different conclusions about the neural basis of the semantic store (A. J. Martin, 2007; Patterson, Nestor, & Rogers, 2007).

The semantic system lies at the intersection of sensory processes and behaviours, both verbal and non-verbal, and is crucial for many aspects of cognition, including verbal comprehension, speech production, visual object processing and even basic colour perception. This central role of semantics in guiding perception, thoughts and behaviours is reflected in the range of articles included in the special issue. We have grouped the articles into (i) work examining the structure and organisation of conceptual knowledge in the brain, (ii) studies of brain networks that support different aspects of semantic cognition – i.e., the use of knowledge to drive appropriate mental processes and behaviours and (iii) papers that

consider the interaction between semantic representations and language or perceptual processes. These are three research topics that have evolved rapidly over the past few decades. Below, we discuss the contribution of the papers in the special issue to our understanding in each of these areas.

Several authors investigated aspects of the *structure and organisation of conceptual knowledge* in the brain. **Luizzi et al.** explored the neural coding observed in the left perirhinal cortex with regard to semantic representation across modalities. They utilised multi-voxel pattern analysis of fMRI data comparing the observed voxel activation similarities to a semantic representational matrix derived from a large-scale norming study. Luizzi and colleagues found that the perirhinal activations were correlated with semantic structure but only when the stimuli were written rather than spoken words. This might suggest that the left perirhinal cortex is not a multimodal semantic region as proposed by some semantic theories but has a more modality-specific character.

Fernandino et al. also used fMRI to collect activation data in response to individual words. They constructed a predictive model of brain activation based on information about the relevance of various sensory-motor domains to the meaning of each word. The model predicted activation to eighty new concrete words at an above-chance level but, as expected, could not successfully predict activity in response to abstract words. This work underscores the important contribution made by sensory-motor information to the representation of concrete words.

Leshinskaya et al. were interested in the representation of abstract functions, such as "to decorate" and "to protect". The action associated with these goals depends on the context – the same actions are not required to protect your body from the cold and to protect objects from flooding. Leshinskaya et al. used a searchlight multivariate pattern analysis to examine abstract goals across two different contexts. They found that anterior inferior parietal lobe represented abstract goals even though these goals did not share specific actions. They concluded that this region contributes to the representation of functional knowledge beyond actions per se.

Musz and Thompson-Schill took a different perspective on the nature of semantic representation, investigating variability in the neural responses to particular words. It is well-known that different aspects of a word's meaning can be emphasised when it is used in different situations. Musz and Thompson-Schill explored the neural basis for this variability by presenting the same words to participants in the scanner in various different contexts. They found that the degree of neural variability for each word was correlated with the degree of contextual variability in meaning (derived from analyses of text corpora). Polysemous words with multiple meanings exhibited higher levels of neural variability. This work potentially has important implications for MVPA studies of semantic representation, which typically treat any variations in signal across word presentations as noise. This variation may in fact represent meaningful changes in mental representation.

The role of context in shaping semantic representations was also integral to the work reported by **Sadgehi et al**. These authors made use of latent semantic analysis (Landauer & Dumais, 1997), a technique that derives semantic representations based on information about their contextual co-occurrence. Latent semantic analysis is typically

applied to co-occurrences of words in text corpora. Sadeghi et al. applied the same technique to non-verbal data about co-occurrences of objects in visual scenes. The resulting representations captured within-category relationships as well as cross-category semantic associations.

Gotts et al. were also interested in mental representations for visually-presented objects. They used fMRI to investigate changes in the "conceptual tuning" of brain regions when the same pictures were presented repeatedly. As demonstrated previously, repeated presentation led to reductions in activity in regions associated with visual processing. In the left prefrontal cortex, however, it also led to broadening of the neural response, such that suppression was also observed for semantically-related images. The authors also found that repeated picture naming led to enhanced behavioural semantic priming effects, also consistent with broadening of the semantic field following repeated processing.

A second key issue examined by many studies in this special issue is the question of *how networks of brain regions co-ordinate to support semantic processing* of various kinds. **Bašnáková et al.** explored the neural correlates of understanding a speaker's intended message, particularly with regard to the situation when the implied message is different from the superficial meaning of the utterance. They explored this important social aspect of language through fMRI data which was collected whilst participants were required to comprehend the replies to interview-style questions. Bašnáková and colleagues found that the fMRI data revealed enhanced engagement of the 'mentalizing network' when speakers had given 'face-saving' indirect replies to the posed questions, indicating an important relationship between emotion and language networks in processing human communication.

Krieger-Redwood et al. investigated the neural basis of association judgements when concepts were presented as pictures and words using fMRI. These judgements were either to pairs of items that were highly related or they were only distantly related (and required more controlled retrieval). There were effects of semantic control demands across modalities in left mid-inferior frontal gyrus (IFG), consistent with the deficits for words and pictures that follow stroke to this region. There were also graded effects of modality in left and right posterior IFG, in areas that were recruited to support phonological judgements. Finally, the study replicated the finding that more anterior areas are less responsive to non-semantic control demands and these regions, together with pMTG, showed a preference for verbal associations. This study speaks to the distributed networks of brain regions that support different aspects of semantic and executive control.

Halgren et al. took a different approach to understanding brain networks that support semantic cognition. They recorded from microelectrode arrays in patients with epilepsy and examined the generation of theta cycles in the temporal and frontal lobes and their potential role in lexical-semantic processing. Theta was generated by alternating current sinks in middle and superficial cortical layers. Additional recordings suggested that theta may be reset by the presentation of words. These findings have potentially important implications for understanding how semantic retrieval can be maintained and also interrupted by new inputs that require different features to be retrieved.

Geranmeyah et al. contrasted the potential roles of left anterior temporal regions and angular gyrus in the semantic aspects of speech production. Following a series of recent

innovative studies by this group, Geranmeyah et al. used task-based ICA of fMRI speech production data to explore this important question. They found that the anterior STS region was connected to Broca's area and other speech-related systems. In contrast, an inferior parietal area was linked to perceptual regions and thus only the anterior temporal regions seem to be implicated in semantically-driven speech production.

Catricalà et al. also investigated activations associated with semantically-driven speech, but did so through the exploration of fMRI picture naming and word reading data collected from patients with amnestic MCI, utilising both direct subtraction analyses and graph analysis to investigate any changes in network function. Catricalà et al. found that the patterns of activation were similar across the two groups although there was some evidence of augmented engagement of left posterior fusiform by the aMCI group when processing the most demanding items, which might reflect some kind of compensatory process.

The anterior temporal lobe (ATL) was the focus of **Sanjuán et al.**'s study. These authors concentrated on distinguishing between the function of two neighbouring regions of the left lateral ATL: the polar termination of the middle temporal gyrus and a more superior region within the superior temporal sulcus. Using fMRI in healthy participants, they found that both regions responded to multi-modal (receptive) semantic judgements but only the more superior region was activated during an object naming task. This latter result might reflect the region's involvement in speech production or the need to retrieve more specific concepts during naming tasks.

The role of *left and right ATL in semantic processing* is a subject of active debate (e.g., Gainotti, 2012; Rice, Lambon Ralph, & Hoffman, in press) and three studies in the present issue have explored this topic in different ways. **Bonnì et al.** used a form of rTMS, continuous theta burst, to modulate activity in left and right ATL and a control site (vertex), and examined the effects on picture and word semantic judgements in healthy participants. Picture judgements were faster after cTBS to right ATL, consistent with the possibility of some specialisation of function by modality across the hemispheres in ATL.

Binney and Lambon Ralph used fMRI to investigate the neural consequences of rTMS to the left ATL. They found that low-frequency rTMS of the left ATL induced a combination of local suppression at the site of stimulation as well as compensatory up-regulation in the contralateral ATL. As well as providing insights into the dynamic collaboration between core regions, the ability to observe intrinsic and induced changes *in vivo* may provide an important opportunity to understand the key mechanisms that underpin recovery of function in neurological patient groups.

Finally, **Patterson et al.** took a neuropsychological approach to the issue of laterality effects in the temporal lobes, reporting data from two unusual patients with extensive temporal lobe damage confined to the left hemisphere. Patterson et al. compared the cognitive profile of these two cases with that seen in semantic dementia, which is characterised by bilateral ATL damage. Both patients exhibited semantic deficits that were most severe for tasks requiring speech production. Interestingly, strong effects of familiarity and typicality, which are consistently observed in semantic dementia patients (cf. Rogers et al., this issue), were present in these cases only during speech production tasks.

A series of other studies also investigated semantic deficits in patients with a variety of aetiologies and areas of brain damage. **Wright et al.** focused specifically on the effects of damage to peririhinal cortex to semantic task performance. Their study utilised advanced neuropsychological methods, in which detailed structural neuroanatomical MRI scanning is combined with careful behavioural testing and innovative feature-based analyses of concepts. Wright and colleagues found that damage to perirhinal cortex was correlated with behavioural impairment on semantic tasks particularly when the tasks probed semantically-confusable concepts.

In contrast, **Mirman et al.** explored lesion-deficit correlations across the whole brain. They used factor analysis of behavioural data from 99 participants with aphasia combined with voxel-lesion symptom mapping to investigate the neural basis of speech production and comprehension deficits. While semantic errors in picture naming were associated with damage to left ATL, verbal and non-verbal semantic recognition were associated with the integrity of white matter tracts in the frontal lobe. The authors suggest that since comprehension draws on a set of widely-distributed cortical areas, the integrity of white mater tracts is likely to be crucial to explaining semantic deficits.

Rogers, Patterson, Jefferies and Lambon Ralph used a comparative case-series approach to contrast the effects of bilateral ATL damage in semantic dementia with that a series of patients with multi-modal semantic deficit following stroke, a presentation termed semantic aphasia and associated with poor executive regulation of semantic knowledge. In accordance with the proposed storage vs. control distinction between these two sets of patients, they found that while semantic dementia patients exhibited consistent effects of concept familiarity, typicality and specificity, these effects were variable and task-dependent in semantic aphasia.

Hoffman et al. also studied patients with semantic dementia, but were concerned with factors influencing "relearning" of object names lost during the course of the disease. They found first that varying the experience during training, by shuffling the order of the items in each session, improved relearning outcomes. In a second study, they found mixed effects of conducting training with multiple exemplars of each object. This improved generalisation to new examples of the trained objects, but with the cost that one patient began to incorrectly "over-generalise" the names she had learned to other objects.

The final trio of studies in this special issue were concerned with the *relationship between semantic impairment and other aspects of language and cognition*. **Woollams** investigated the effect of imageability on word reading in semantic dementia. Patients demonstrated more intact reading for low imageability words, which runs counter to the high imageability advantage observed in healthy participants. Woollams suggests that this finding has important implications for models of reading, particularly those that envision a role for semantic knowledge in supporting spelling-sound conversion (Plaut, McClelland, Seidenberg, & Patterson, 1996). Due to their weak semantic representations, reading of low imageability words may rely minimally on semantic support, such that semantic impairment paradoxically produces less impairment for reading these words.

Meteyard et al. studied the relationship between semantic and phonological processing in aphasia, using iconic words like "moo" and "splash" which have a systematic

connection between semantic features and phonology. Patients with aphasia were given tests of repetition, reading and lexical decision, for iconic and non-iconic control items. The patients showed a processing advantage for ionic words in repetition and auditory lexical decision, reflecting the strong connection between semantics and phonology in these tasks.

Finally, **Rogers, Graham and Patterson** explored the effects of semantic impairment in semantic dementia on colour processing. Basic colour perception was intact in their patients but categorisation and naming of colours was impaired. Surprisingly, Rogers et al. found that this impairment was specific to secondary colours but did not affect processing of red, blue or green. These results are indicative of the profound influence of semantic knowledge on visual processing but they also demonstrate the limits of this influence.

As we hope this brief meander through the contents of this special issue demonstrates, this is an exciting time to be working in the field of semantic cognition. The methods and range of data at our disposal have never been broader or more sophisticated and they are being applied in new and creative ways. In putting together this special issue, however, we have been pleased to see that more traditional behavioural neuropsychological studies continue to flourish. Such studies, we believe, will always have an important role to play. They have obvious clinical value in characterising the multifarious nature of semantic impairment across many disorders, but they also provide striking and sometimes counter-intuitive insights into the workings of the semantic system. We hope that neuropsychology remains at the heart of semantic cognition for many years to come.

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References

Gainotti, G. (2012). The format of conceptual representations disrupted in semantic dementia: a position paper. *Cortex, 48*(5), 521-529. doi: 10.1016/j.cortex.2011.06.019

Landauer, T. K., & Dumais, S. T. (1997). A solution to Plato's problem: The latent semantic analysis theory of acquisition, induction and representation of knowledge. *Psychological Review, 104*, 211-240.

Lüders, H., Lesser, R., Hahn, J., Dinner, D., Morris, H., Resor, S., & Harrison, M. (1986). Basal temporal language area demonstrated by electrical stimulation. *Neurology, 36*(4), 505-510. doi: 10.1212/WNL.36.4.505

Martin, A., Wiggs, C. L., Ungerleider, L. G., & Haxby, J. V. (1996). Neural correlates of category-specific knowledge. *Nature, 379*(6566), 649-652.

Martin, A. J. (2007). The representation of object concepts in the brain. *Annual Review of Psychology, 58*, 25-45.

Norman, K. A., Polyn, S. M., Detre, G. J., & Haxby, J. V. (2006). Beyond mind-reading: multi-voxel pattern analysis of fMRI data. *Trends Cogn Sci, 10*(9), 424-430. doi: 10.1016/j.tics.2006.07.005

Patterson, K., Nestor, P. J., & Rogers, T. T. (2007). Where do you know what you know? The representation of semantic knowledge in the human brain. *Nature Reviews Neuroscience, 8*(12), 976-987.

Petersen, S. E., Fox, P. T., Posner, M. I., Mintun, M., & Raichle, M. E. (1988). Positron emission tomographic studies of the cortical anatomy of single-word processing. *Nature, 331*(6157), 585-589.

Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review, 103*(1), 56-115.

Rice, G. E., Lambon Ralph, M. A., & Hoffman, P. (in press). The Roles of Left Versus Right Anterior Temporal Lobes in Conceptual Knowledge: An ALE Meta-analysis of 97 Functional Neuroimaging Studies. *Cerebral Cortex*, bhv024.

Shimotake, A., Matsumoto, R., Ueno, T., Kunieda, T., Saito, S., Hoffman, P., . . . Takahashi, R. (in press). Direct exploration of the role of the ventral anterior temporal lobe in semantic memory: cortical stimulation and local field potential evidence from subdural grid electrodes. *Cerebral Cortex*, bhu262.

Walsh, V., & Cowey, A. (2000). Transcranial magnetic stimulation and cognitive neuroscience. *Nature Reviews Neuroscience, 1*(1), 73-79.

Warrington, E. K. (1975). The selective impairment of semantic memory. *Quarterly Journal of Experimental Psychology, 27*, 635-657.

Wernicke, C. (1874). [Der Aphasische Symptomencomplex].

Wise, R., Chollet, F., Hadar, U., Friston, K., Hoffner, E., & Frackowiak, R. (1991). Distribution of cortical neural networks involved in word comprehension and word retrieval. *Brain, 114*(4), 1803-1817.